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Computer Systems and Communications

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A SATELLITE MAIL PROPOSAL

from J. H. Saltzer

Attached is a paper, just received, by Ramani and Miller, proposing a low-orbit satellite with on-board storage to be used as a world-wide message relay service. Ramani has inquired if we might have any interest in participating in the development of this idea.

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A new type of communication satellite needed for computer based messaging

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Abstract

Computer mediated communication systems, specifically those that offer a form of electronic mail and computer conferencing, are difficult to implement in areas where no public data networks exist. Even where the PDNs exist, these systems can benefit from the use of more appropriate communication techniques. The use of an inexpensive communication satellite in a low level orbit (100-5000 kms high), operating a relatively narrow band transceiver (offering 64 KBPS to 256 KBPS of throughput) is proposed. It would employ a frequency below 3000 MHz to enable the use of antennas with low directivity and the use of low cost direct reception equipment on the ground. The satellite would carry an on-board computer. Polling ground stations in the order of longitude as it passes, it would collect and store messages which it would distribute around the world. A very high message handling capability (several hundred million messages/year, averaging several hundred characters each) is visualized. A valuable application would be in modernising telegraphy and in creating new facilities appropriate to advanced telegraphy systems. Keeping telegraphy alive and improving it to meet primary communication needs is of special interest to developing countries [1] till such time they are able to offer widespread, low cost telephony.

1. Introduction

The essence of computer mediated communication, both in messaging and in computer conferencing, is asynchronicity [2] and the automation of filing, indexing, copying and notification aspects. By buffering messages, such a system eliminates the need for communicants to be on-line simultaneously. Offering written (and automatically filed) records of all messages, they facilitate a reliable, convenient mode of communication in which there is time to create responses after deliberation, unlike the case in telephony. Requiring an effective throughput of only a hundred bits per second to carry all that a person could dictate at full speed, they offer a tremendous economy in transmission requirements. It is worth noting that a keyboard operator working at full speed produces a net output of only 40 BPS. An electronic teleprinter receiving messages at 100 BPS can print out one 100-word message every minute. The contrast with voice communication is best illustrated by considering the current annual telegraph throughput of a typical country, of the order of a few hundred million telegrams per year. If all these telegrams were to be transmitted through a single channel, a transmission capacity of 64 KBPS, normally used to carry one voice channel in the PCM format, would be more than adequate for the purpose.

But, traditionally, message systems have had to suffer all the problems and overheads of voice communication. In most areas of the world, access to computer conferencing systems involves the use of an analog telephone network through modems, even though key segments of such a network may be employing PCM transmission at 64 KBPS, two way, but delivering only an effective throughput of 100 BPS*, one way. An undue dependence on interfacing to a telephone network not originally designed with this application in mind creates a variety of problems. Local access arrangements based on good quality local cables, switching equipment, modems, etc. become essential. The user usually has to cope with an immoderate tariff for long distance transmission (up to 4 US $/minute over long distances).

2. Sub-synchronous Satellites

Communication satellites have not so far eliminated these problems in messaging, mainly because they have been designed, again, without this applicaton in mind. Because of this, it is necessary to investigate new types of communication satellites.

Consider a message switch in a sub-synchronous orbit. With its on-board memories, it can store and forward messages. Instead of using a transponder, it will use a transceiver, communicating purely in digital format. Signals will then do only a one way trip at a time, either up-link or down-link before the signal is regenerated. This feature, and those covered below in Sec. 2.2, vastly simplify communication design problems, permitting the use of low power transmitters and simple antenna systems.

2.1 Global distribution: The very fact that such a satellite will not be stationary at any longitude will become its strength. Orbiting the earth every few hours, it would be able to distribute messages globally without extensive inter-network connections otherwise required.

2.2 Narrow bandwidth and power requirements: Since the information to be communicated is very compact, a few thousand bits per message, a single 64 KBPS transceiver seems adequate to meet the needs of thousands of small earth stations. Typically earth stations would range from single terminal micro/mini computers equipped with individual transceivers, to larger computer systems with an average of 20 to 30 terminals per transceiver. Each earth station computer would offer message preparation facilities and have

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* Limited by key boarding and printing speeds at the terminal, as well as the reading speeds of users.

software/hardware to handle relevant communication protocols. Assuming net throughput through the satellite to be 100 BPS per active terminal, it is clear that several thousand terminals could use a single satellite of the type envisaged.

The narrow bandwidth required will make it possible for the satellite and earth stations to use low power transmission and to use relatively low (possibly VHF or UHF) frequencies. The earth stations will need only to use inexpensive transceivers. The fact that the satelite will be ten times nearer, at the moment of communication, than a geosynchronous satellite will also contribute significantly to the reduction in power requirements.

Earth stations would be able to use directional antennae, pointed due south (in the Northern hemisphere) or in a direction west of south. With a lobe 10 to 30 degrees wide between 3 dB points, such antennae will reduce power requirements further, without unduly restricting communication. Transmitted power of the proposed satellites could be in the range from 1 to 20 watts. The transmitter need not be continuously on and would be kept completely off, for instance, during major ocean crossings, and over all territory where there are no participating earth stations.

2.3 Direct reception from satellite: The greatest benefit to be conferred by the proposed system will be the nature of the communication access offered: direct reception from satellite, making it possible to reach, at very low cost, remote areas and other areas where traditional data communication is difficult or impossible.

2.4 Attitude control: If non-directional antennae are employed in the satellite, attitude control requirements would be vastly simplified, leaving only the requirements of pointing the solar panels properly. On the other hand, attitude control could be helpful, enabling the use of directional antennae, reducing power requirements further. In any case, the beams would not be narrow beams and only coarse attitude control would be required.

2.5 Control and security aspects: The large number of earth stations in the proposed system poses new, but not intractable, problems. How does one prevent unauthorized access? How does one safeguard against a transceiver on the ground getting stuck in the 'on' position?

Apart from usual telemetry/telecommand channels, there is need for a communication control channel. A control station, using a highly directive antenna, would use this channel to pass on control information to the on-board computer. For instance, such transmission would carry individual keys to be used in encrypting the up-link and down-link for each transceiver on the ground. Using any simple encryption scheme, the system could easily attain a high degree of protection from individuals, though not from professional cryptanalytic attacks by major agencies.

The satellite would poll earth stations in the order of their longitude as it passes, to collect messages and repeat this polling a few times during the visible period each pass over a station. It would use an internal clock and its own longitude counter maintained by the on-board computer, corrected once each orbit by the control station. At each polling time, the satellite should report to each earth station, as a security measure, the last message number received from that station and the time of last contact. If unauthorized access does occur, this arrangement will facilitate prompt discovery. Routine statistical reports concerning all earth stations should be sent by the satellite to the control station each time it passes over it, to help in monitoring and management.

Special design features could be incorporated into the earth station transceivers to make it impossible for them to be stuck 'on'. An output monitoring arrangement, in hardware or software, which automatically detects this condition and triggers an isolator is worth considering.

In applications requiring more than routine precautions against unauthorized access, techniques such as spread spectrum communication may be considered.

<u>2.6 Orbit size:</u> The orbiting altitude will have a major effect on the performance of the satellite proposed (see Figs. 1 and 2). At a higher altitude, the satellite would be visible for a longer period each pass, but the passes would be separated by many hours.

Within a small/medium sized country, a visible period half an hour long or more would confer special benefits. All messages transmitted during this period for delivery within the same country/region would be delivered with almost no delay. On the other hand, a low orbit reduces the guaranteed delivery time, making it as low as a hundred minutes. Figs. 1 and 2 illustrate the relationship between satellite altitude and delivery time. They also provide other information, such as visibility of satellites at different latitudes away from the equator. Theta, in the figures, indicates the latitude upto which equatorial satellites are visible for a given altitude. Minimum elevation angles necessary for good reception and refraction effects need to be taken into account in discussing high latitude stations.

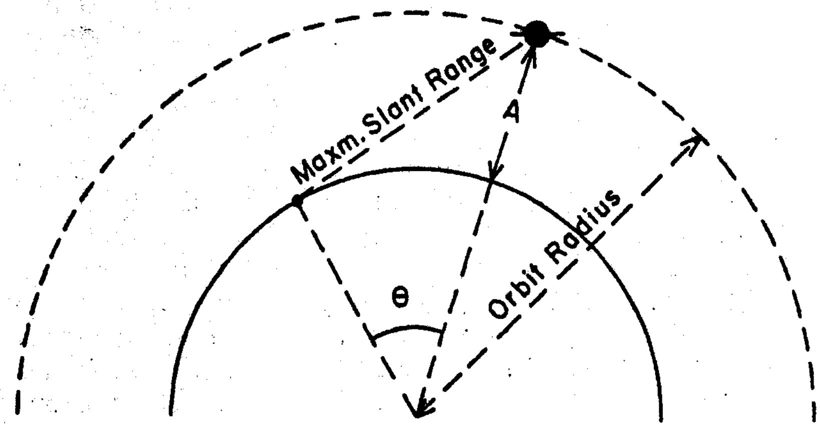

Fig.1 Orbit Size and Visibility

Formulas used to compute parameters in Fig. 2:

$$\text{Real Period} = 84.49 \left(\frac{A+R}{R}\right)^{3/2} \text{ Minutes [4].}$$

Theta, the highest latitude at which the satellite is visible,

$$= \cos^{-1}\left(\frac{R}{R+A}\right)$$

R being the earth's radius, taken as 6378 kms.

Fig.2 Altitude vs Visiblity

Altitude A	Orbit Radius R	Maxm Slant Range	Theta in degrees	Visible Time	Real Period	Visible Time for Pass
300	6678	1979	17.2	9.6%	90.5 mts	8.7 mts
500	6878	2574	22.0	12.2%	94.6 mts	11.4 mts
1000	7378	3708	30.2	16.8%	105 mts	17.5 mts
1500	7878	4624	35.9	19.9%	116 mts	23.1 mts
2000	8378	5432	40.4	22.4%	127 mts	28.3 mts
2500	8878	6175	44.1	24.5%	139 mts	33.9 mts
3000	9378	6875	47.1	26.2%	151 mts	39.6 mts
4000	10378	8186	52.1	28.9%	175 mts	50.7 mts

Notes

1. Distances are in kilometers.
2. Visible time given in the last column holds only for locations on the equator. However, 'visible time' does not fall sharply with latitude till limiting latitudes are reached.

An interesting possibility is the use of two or more satellites. This will require the software on the ground (see Section 3) to be a bit more complex, to take different message sequence numbers into account. Inter-satellite communication would be the next feature to be considered in such a design. The narrow bandwidth links necessary can be established with great ease compared to high bandwidth links between geo-stationary satellites handling voice bandwidth signals. A satellite moving east to west, if possible, would complement a conventional satellite very well for delivery of international messages [5].

With multiple satellites, it may also be worth considering the use of relay stations on the ground meant to facilitate inter-satellite traffic of messages. They could reduce on-board storage requirements and act as intelligent intermediaries in inter-satellite communication.

3. Ground Equipment

Each earth station will have a transceiver connected to a microprocessor which would run special software to control the equipment. Possibly using a yagi antenna, the transceivers would transmit on a specified up-link frequency, different from the down-link frequency, offering the usual benefits of isolating signals going up from those going down. Transmission would be rigidly controlled by polling commands from the satellite asking a station to send at a strictly specified time. Using a programmable real-time clock synchronized by software to time signals from the satellite, the microprocessor would carry out these commands, thereby adopting a reservations technique [3] for time assignment. After sending a message segment, a few hundred characters long, an earth station would indicate if it had anything more to transmit, further segments of the same message or those of another message. The microprocessor would also be carrying out monitoring and diagnostic functions to ensure trouble-free operation of the whole earth station, giving suitable indications to the control station or to the local user as appropriate.

The use of a reservations technique will make it possible to obtain a high throughput. The microprocessor could also implement text compression algorithms, possibly offering an increase of 30% to 50% greater throughput and on-board message storage using the same hardware configuration (shortening of messages by text compression would actually save storage both on ground and on the satellite).

3.1 User facilities: The user would need message preparation facilities, on-line filing and indexing facilities, conferencing facilities and would require hardcopy output facilities, frequently on office quality output devices. It seems ideal that these functions be separated from those of a communication control microprocessor which would be identical in all user installations. Messaging and conferencing facilities could be provided in a variety of ways by employing one-user micro computers or multi-user computers of different sizes. The interfacing between the microprocessor and the user computer should ideally be a simple standard 25 pin interface that is used between data terminal equipment and modems. However, no modems would be required on these links which would operate under a standard hand-shake arrangement.

Interface speeds of 300, 600, 1200, 2400, 4800 and 9600 BPS seem ideal, with a speed selection arrangement to suit the needs at each location. An additional current loop interface at 50/75/100/200 BPS seems profitable to have, to connect teleprinters using the 5 bit alphabet. The microprocessor should also be able to accept messages, prepared in a standard format, directly from a terminal or a teleprinter and should not make a messaging system computer essential at all locations.

4. The on-board computer

The computer on-board the satellite should ideally be capable of storing all the messages it receives in one orbit period. At 64 KBPS, 50% duty factor, this would be 15 or 20 megabytes. This is not, however, a rigid requirement. Depending upon the traffic expected, altitude, distribution of earth stations on the ground, nature of traffic, etc., an on-board storage in the range of 1 to 5 megabytes could be chosen. Note that traffic within a region need not be stored over an orbit, as it can be switched more or less instantaneously. On-board storage should be in the form of a semiconductor memory built out of RAMS, or be a bubble memory system. In view of the small physical size involved, radiation shielding seems to pose no problems.

The on-board computer would handle communication with the control station, communication protocols and polling, message reception, storage and transmission. It will also generate periodic statistical reports.

5. Other considerations

A number of questions need to be examined: for instance, the choice between a single channel and multiple channels for ground to satellite communication. Multiple channels could help in increasing traffic handling capacity and in reducing impacts of equipment failure. But, increase in traffic handling capacity would have to be matched by an increase in the size of on-board memory.

The question of choice of orbit is also interesting. An orbit inclined to the equator can facilitate a low orbit satellite to reach farther north and south, but there will be no guarantee that each earth station would be able to access it once per revolution; but these orbits are attractive when a multiple satellite scheme is visualised. Polar orbits have their advantages, but the cost/benefit ratios may not be all that attractive. Fig. 3 illustrates the effect of having four equatorial satellites. For stations at low latitudes, at least one of the four satellites will be visible at any given time. With inter-satellite relay, it will then be possible to provide for no-delay communication between any pair of locations at low latitudes. Similar configurations may even permit on-line data communication between remote locations, in a packet-switching mode.

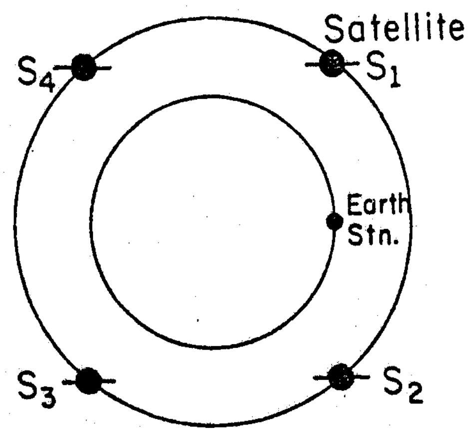

Fig.3 Four Equatorial Satellites

Being in low orbits, the proposed satellites will be in earth shadow for several hours a day. But, because of low power requirements, this is not expected to pose a major problem. Further, it should be noted exposure to Sun and shade alternate regularly every two or three hours; the period in shade per revolution is half an hour or less. Satellite design from the point of view of power to be used and from that of cost is a critical area which needs attention.

6. Applications

The technology proposed here could revolutionize telegraphy and create modern forms for it. Its impact should be particularly high in the developing world, not too far from the equator. New forms of telegraphy, offering transmission in 7 bit alphabets and in local scripts can be created. Extension to facsimile transmission is a clear possibility, subject to on-board storage limitations. By making possible several thousand low cost earth stations per satellite, remote and rural areas can be brought the benefits of low cost communication. Message relay in Telex and in similar systems is another possibility. In industrialized economies, this low cost technology may hasten the arrival of the office of the future, vastly reducing the use of paper and lowering the significance of distance as a factor in communications.

A major application of the proposed satellite could be to offer a "broadcast videotex" service. A hundred pages of information, possibly incorporating graphics, could be transmitted simultaneously to all users in a region in 5 to 10 seconds. Special techniques relevant to broadcast videotex, such as selective updates of part of the stored information, economic encoding of graphic primitives etc., could be used with profit.

Common interest groups who might be interested in adopting this technology would include airlines, banks, shipping and oil companies, international bodies in science/education/culture, scientific cooperation groups, inter-university groups, etc. Defence applications are obvious, but it should be noted that this proposal offers an opportunity to redirect what is partly a military technology to peaceful applications.

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